

**JANUARY 2008 ESTIMATES  
OF DECADAL CLIMATE AND BUILDINGS CODE CHANGES  
OVER THE GLOBE**

by

Charles H. Whitlock, William S. Chandler, James M. Hoell, David J. Westberg, and  
Taiping Zhang  
Science Systems and Applications, Inc., Hampton, VA, 23666-5845

Paul W. Stackhouse Jr.  
Mail Stop 420, NASA Langley Research Center, Hampton, VA 23681-2199

A Special Report for the ASHRAE Technical Committee 4.2 on Climatic Information  
2008 ASHRAE Winter Meeting  
New York City, NY  
January 19-23, 2008

Sponsored  
by the  
NASA Applied Sciences Program, Earth-Sun System Division

## INTRODUCTION

As part of the 1958 Space Act as amended [Article 203(a)(4) and Article 203(b)[(2) Section 9)], NASA has been instructed to assist the buildings industry by enhancing the accessibility of historical and near real time environmental data currently contained within NASA's data archives. The NASA Prediction Of World Energy Resources (POWER) project became aware of long-term needs in the buildings industry at a meeting in Charlottesville, VA in June of 2001. Attending were representatives from William McDonough + Partners (an architectural firm), 2rw Consultants, Inc. (an engineering firm), Old Mill Power Company (a renewable energy firm), and the Assistant Dean of the School of Engineering at the University of Virginia. Their major concern was the time it took to obtain weather and solar radiation data for a foreign country, particularly if the location is in a rural, underdeveloped area. Often, there was a 60-day period to submit a preliminary-design proposal. It was taking that long to obtain some foreign weather or radiation information. The national need was for a quick look at preliminary weather and radiation data to develop preliminary building designs within a short proposal time limit. Several U.S. and international government agencies had the same requirement. Over the past 10 years, NASA has supplied global data to the World Health Organization, the United Nations, Natural Resources Canada, and two U.S. Department of Energy laboratories. Requests for some buildings- and agricultural-related parameters have also come from private, academic, and commercial users of its Surface meteorology and Solar Energy (SSE) web site (<http://eosweb.larc.nasa.gov/sse>). As a result, the web site now provides global information on many renewable energy parameters and a few buildings-related items. NASA is now coordinating with ASHRAE to determine if recently-developed and/or future weather and climate parameters may be of use to that international society.

ASHRAE Technical Committee 4.2 has discussed changing the duration of ASHRAE ground site data from 30 years to a shorter period in the 10- to 12-year range. This might allow quicker indications of regional global warming and cooling changes in coming decades. This document presents a few examples of how the data in the SSE data portal can provide early information on climate change for buildings-related weather parameters over the past two decades. More specifically, this report provides a graphics review of July all-sky solar insolation, July cooling degree days, yearly moisture climate types, and Briggs et al. climate zones for two different decades (1983 – 1993 and 1993 – 2003). All results presented are based on 1.0-deg spatial resolution latitude/longitude cells (~60 x 40 nautical miles at mid-latitudes) that are at a cell-averaged topographic height above sea level based on USGS data.

An uncertainty analysis of the present NASA GEOS-4 reanalysis temperature data is presented because it influences estimates of the DOE/ASHRAE Briggs et al. climate zone boundaries. In this report, examples of approximate lapse-rate corrections that have been applied to existing 1-deg cell size GEOS-4 data are presented. Future 0.5-deg spatial resolution versions combined with lapse-rate corrections in mountain and valley regions are expected to further improve accuracy.

## DECADAL CLIMATE CHANGES

Using the extended time history of the global solar data in the SSE archive, one can quickly ascertain how the surface insolation for any location in the world might be changing. For example, the decadal averages in the July all-sky (monthly-average mixed cloudy and clear conditions) solar insolation for the United States (U.S.) are shown in Figure 1. The top panel of Figure 1 shows the July insolation for the years 1983- 1992 while the bottom panel is for the years 1993 – 2003. A clearer assessment of the differences between these two decades is evident from the top panel of Figure 2, which shows the difference between the July decadal averages. The bottom panel of Figure 2 provides the July decadal difference for the entire globe. A more detailed analysis for a given geographical region including additional monthly and/or seasonal averages can easily be performed using the tools provided in the SSE website.

Figures 3 and 4 show both U.S. and global decadal averaged July cooling degree days. In general the decadal differences appear small over most of the globe during this period, however from the more detailed view of the US in Figure 3, one can clearly discern regions where changes in the cooling degree days have occurred (e.g. the southwest US and Gulf of Mexico). Here again, a more detailed analysis of specific geographical region can performed using the data and tools provided in the SSE website.

In Figure 5 we show the July decadal average in yearly moisture climate type. The top panel is the July average for 1983 – 1993; the bottom panel the July average for 1993 – 2003. The three moisture types, dry, humid, and marine, are based on data from the World Climate Research Program (WCRP) Global Climatology Project (GPCP). Even on a global scale, differences between the top and bottom panel can be seen suggesting that changes in the moisture climate types may be occurring in some regions.

July Decadal averages for the Briggs et al. building climate zones are shown in Figure 6. Calculations are based on Briggs, et al., 2002 (R.S. Briggs, Robert G. Lucas, and Z. Todd Taylor: Climate Classification for Building Energy Codes, Technical Paper Final Review Draft, Pacific Northwest National Laboratory, 34pp, March 26, 2002, [http://www.energycodes.gov/implement/pdfs/climate\\_paper\\_review\\_draft\\_rev.pdf](http://www.energycodes.gov/implement/pdfs/climate_paper_review_draft_rev.pdf)). Note that meteorological boundaries without adjustment to political boundaries are shown in Figure 6. Only a few significant differences in the decadal averages are evident on a global scale and over this particular time period. It must be noted that significant year-to-year differences may exist, but they have not been investigated yet.

## GEOS-4 TEMPERATURE UNCERTAINTIES

NASA reanalysis models output meteorological parameters for each cell over the globe on a 3-hourly basis. One function of the NASA POWER Project is to test some of the output parameters against site data at different locations than the sites that were used within the original reanalysis model. We have reported the results of some validation testing to ASHRAE TC 4.2 at previous meetings. As noted in previous reports to

ASHRAE, we rely on international site data obtained from NCDC several years ago. We have elected to use only hourly ground site data that meet the 85% criteria defined in Figure 7 at this time. It is believed that hourly ground site data is the best way to initially validate global maximums and minimums that are output from 3-hourly reanalysis methods.

In Figures 8 – 15, we illustrate results of comparing the 1987 GEOS-4 daily averaged temperatures to ground observations in each of the 8 Briggs et al. climate zones. The daily averaged GEOS-4 temperature is derived from 3-hourly values; the ground based values are derived from hourly observation at NCDC stations that met our 85% criteria. The top panel in each figure shows the location of each NCDC station that meets the 85% criteria for each respective climate zone. Note that different symbols are used, depending on the altitude above sea level shown in the lower left of the map, and that a number of the sites are at high altitude. The bottom panel in each figure shows a scatter chart comparing daily average 2-meter temperatures from the 1-degree GEOS-4 reanalysis model to the NCDC site data. The number of NCDC stations, and number of NCDC/GEOS-4 temperature pairs used in the comparisons is given below in each scatter plot. The color bar indicates the number of ground site points within each color. For example, in Figure 8 the dark blue color represents 27.59% of the data for Zone 1. For this particular case, 72.41% of the sites are fairly close to the line of agreement. Table 1a. below summarizes accuracy in degree C statistics for each climate zone. Topography-based lapse-rate temperature corrections have not been applied to these data.

Table 1a. Accuracy of 1987 Uncorrected Daily Averaged GEOS-4 Temperatures Versus NCDC Site Values							
Climate Zone	Bias ( C )	RMSE ( C )	Slope	Intercept ( C )	Rsqd	TotNoPts	NumStns
ClimateZone1	-2.08	3.18	0.85	2.58	0.71	20050	55
ClimateZone2	-2.08	3.53	0.79	3.45	0.79	25167	69
ClimateZone3	-2.01	3.73	0.89	0.50	0.85	49988	137
ClimateZone4	-1.41	3.49	0.88	0.66	0.89	94804	260
ClimateZone5	-1.22	3.42	0.91	0.08	0.89	113728	312
ClimateZone6	-2.79	4.58	0.94	-1.86	0.89	40466	111
ClimateZone7	-2.96	4.86	0.98	-2.70	0.89	46662	128
ClimateZone8	-3.13	5.65	0.88	-2.93	0.90	23693	65

As noted above, each SSE value, including the GEOS-4 temperature data, is averaged over a 1-degree grid cell. Figure 16 is a schematic chart that illustrating the relative positions of a grid cell and a local site that might occur in mountainous regions. In particular the average elevation of the grid cell may be above (or below) the elevation of the local ground site. It is well known that approximate lapse rate correction techniques can be used to estimate temperatures on mountain tops or in valleys given a temperature value at a known height. Figure 17 demonstrates how lapse rate corrections were used in Idaho to correct original GEOS-4 reanalysis temperatures (pink color) at a higher altitude (1387 m) to the average altitude of three lower-altitude (green color) towns (Parma, Nampa, and Boise) which were at similar altitudes (703 to 829 m).

An approximate lapse rate correction for average temperature has been applied to GEOS-4 data in all climate zones for 1987 on an experimental basis. Altitudes above sea level are given for all NCDC ground site stations, and terrain-average heights of all GOES-4 cells are known within about a meter (Figure 18). Table 1b provides the same statistical results as Table 1a except that the experimental correction has been applied. Accuracies are improved for every climate zone when compared with Table 1a above.

<b>Table 1b. Accuracy of 1987 Corrected Daily Averaged GEOS-4 Temperatures Versus NCDC Site Values</b>							
<b>CLZ1</b>	<b>Bias ( C )</b>	<b>RMSE ( C )</b>	<b>Slope</b>	<b>Intercept ( C )</b>	<b>Rsqd</b>	<b>TotNoPts</b>	<b>NumStns</b>
ClimateZone1	-0.10	1.58	0.84	4.02	0.83	20052	55
ClimateZone2	0.26	2.05	0.87	3.04	0.90	25170	69
ClimateZone3	0.14	2.14	0.96	0.85	0.92	49997	137
ClimateZone4	0.39	2.08	0.98	0.63	0.94	94829	260
ClimateZone5	0.02	1.88	0.99	0.13	0.95	113777	312
ClimateZone6	-0.14	2.34	1.01	-0.20	0.95	40494	111
ClimateZone7	-0.40	2.80	1.05	-0.65	0.94	46684	128
ClimateZone8	-0.24	3.95	0.93	-0.50	0.92	23698	65

The same approximate lapse-rate correction has also been applied for all GEOS-4 data between 1983 and 2006. Results are shown in Table 2 below.

Table 2  
Accuracy of 1983 through 2006 GEOS-4 Temperature versus NCDC Site Values  
For All Climate Zones

	<b>Bias deg C</b>	<b>Rmse deg C</b>	<b>Slope</b>	<b>Intercept deg C</b>	<b>Rsqd</b>
Uncorrected GEOS-4:					
Tavg	-0.55	2.76	1.00	-0.56	0.94
Tmax	-1.82	3.96	0.96	-1.15	0.91
Tmin	0.27	3.47	0.91	0.330	0.99
Corrected GEOS-4:					
Tavg	~0.00	2.42	1.00	-0.04	0.96
Tmax	~0.00	3.28	0.97	0.57	0.92
Tmin	~0.00	3.25	0.99	0.06	0.92

Approximate corrections applied were:

Tavg -5.3 deg C/km GEOS-4 cell-to-site altitude difference  
Tmax -6.1 deg C/km GEOS-4 cell-to-site altitude difference  
Tmin -4.7 deg C/km GEOS-4 cell-to-site altitude difference

Correlation differences between averages, maximum, and minimum temperatures may have been caused by the fact that GEOS-4 values were 3-hourly and NCDC values were hourly. NOAA documentation indicates uncertainty in the ground site data is

approximately 0.5 deg C. Local heat island effects in the site data are not accounted for in the NASA GEOS-4 data and probably cause some of the above differences.

## **CONCLUSIONS**

In this summary report we have only shown examples of how the NASA/SSE data available through the SSE web site might be used to discern decadal differences in parameters of interest to the building community. The decadal climate differences indicated in figures 1 through 6 clearly need further analysis. There may be large deviations in some regions of the globe for only one or two years within each decade. Significant short-term deviations may be of concern to the buildings industry in those regions. Additional buildings-related climate parameters beyond those presented in this document should also be examined.

New reanalysis meteorology with approximately 0.5 degree spatial resolution is now undergoing validation tests within NASA. Initial results indicate improved accuracy over the GEOS-4 results shown in figures 8 through 17 in this document. The smaller spatial resolution should also reduce the need for lapse-rate correction in many regions, and the corrections would be smaller in mountain regions. (We also note that individual uses may be able to apply lapse rates corrections that are more appropriated for their particular geographical region.)

Heat-island effects need serious study on a local basis. Heat island effects may cause larger errors than lapse rate correction uncertainties at some locations, particularly in flat topography.

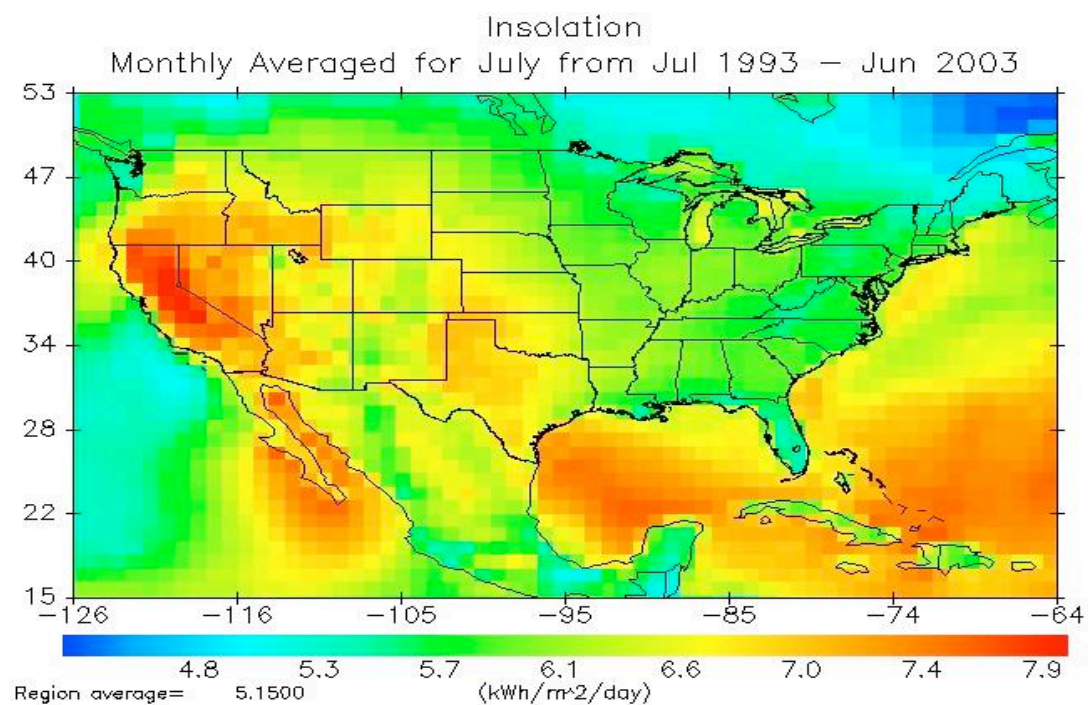
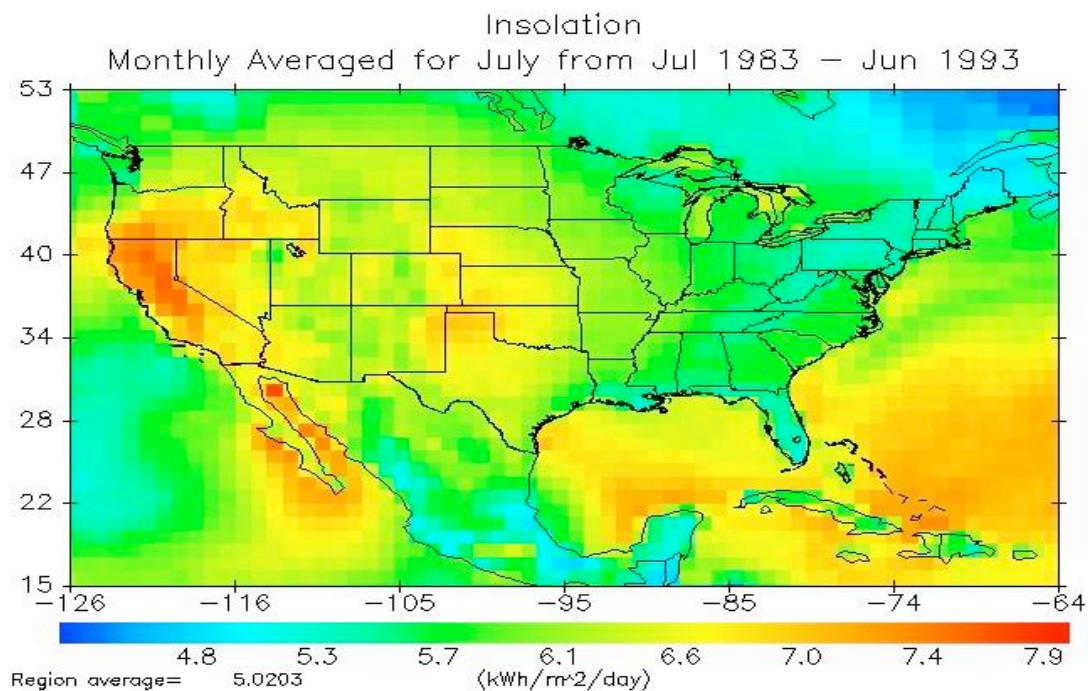


Fig. 1 - 1983 to 1993 and 1993 to 2003 July average all-sky solar insolation for the United States.



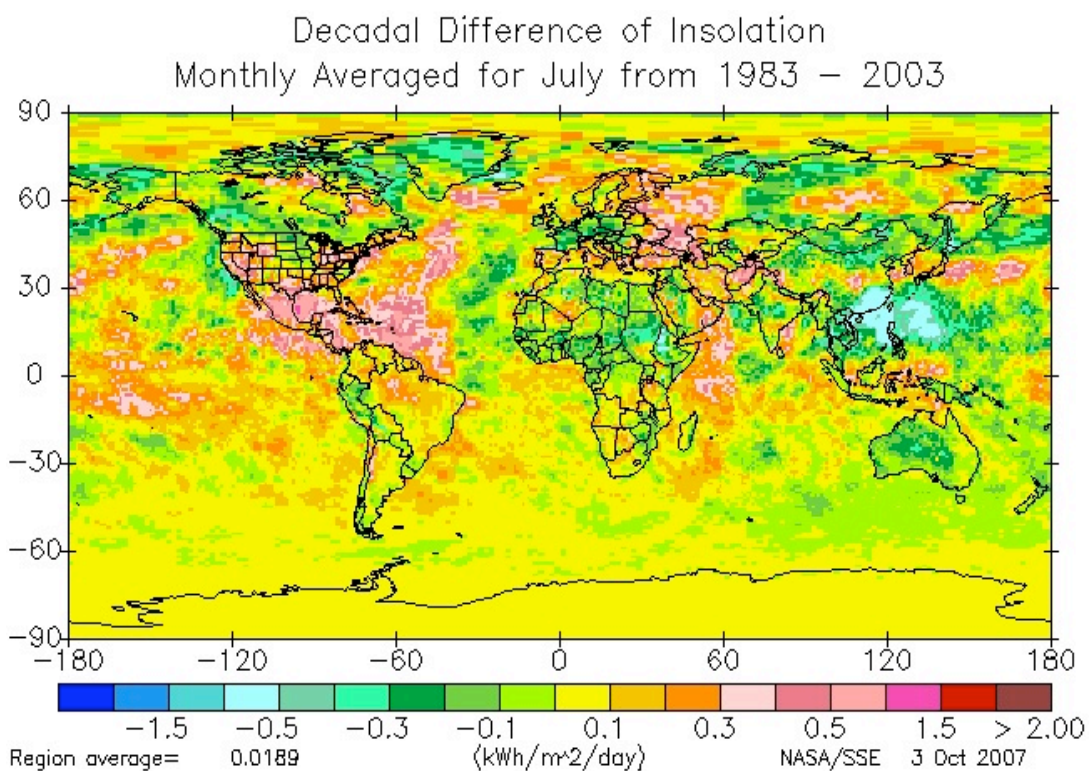
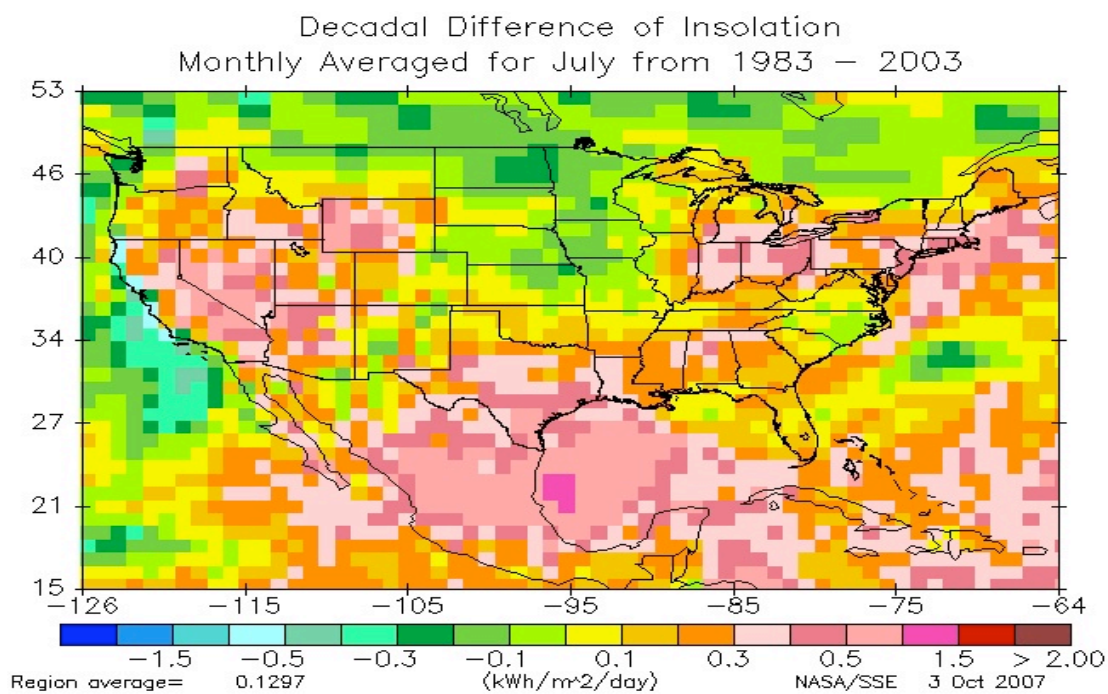


Fig. 2 - 1983 to 1993 and 1993 to 2003 July decadal differences of all-sky solar insolation for both the U.S. and the globe.



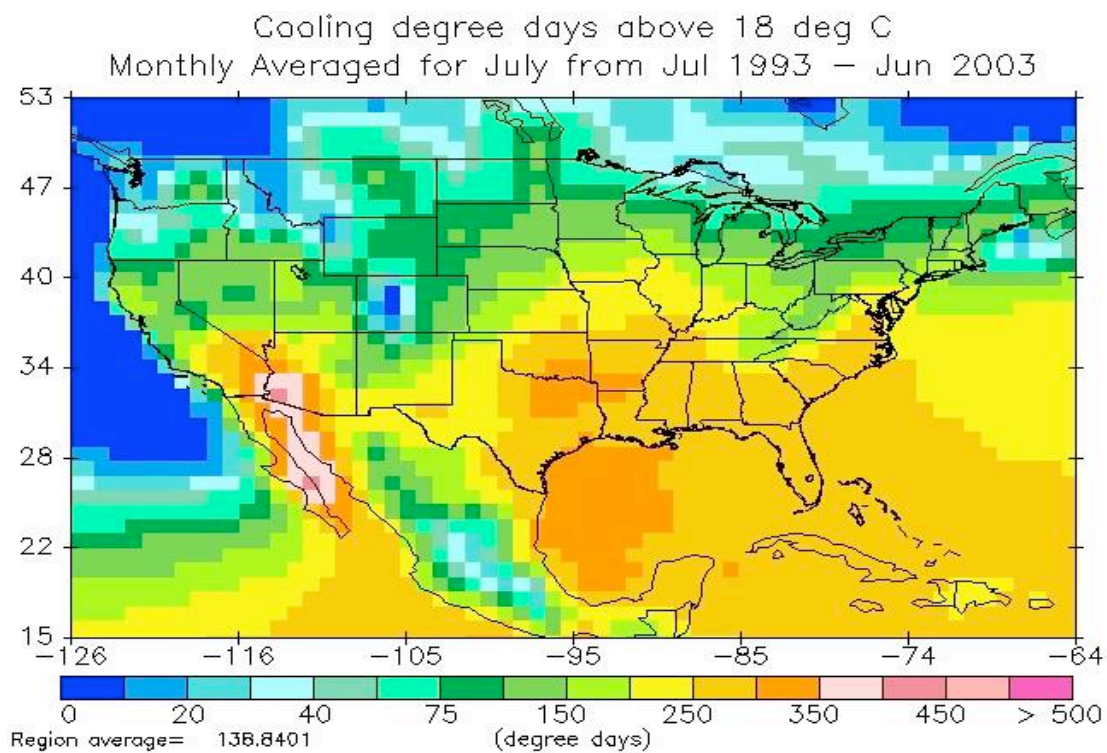
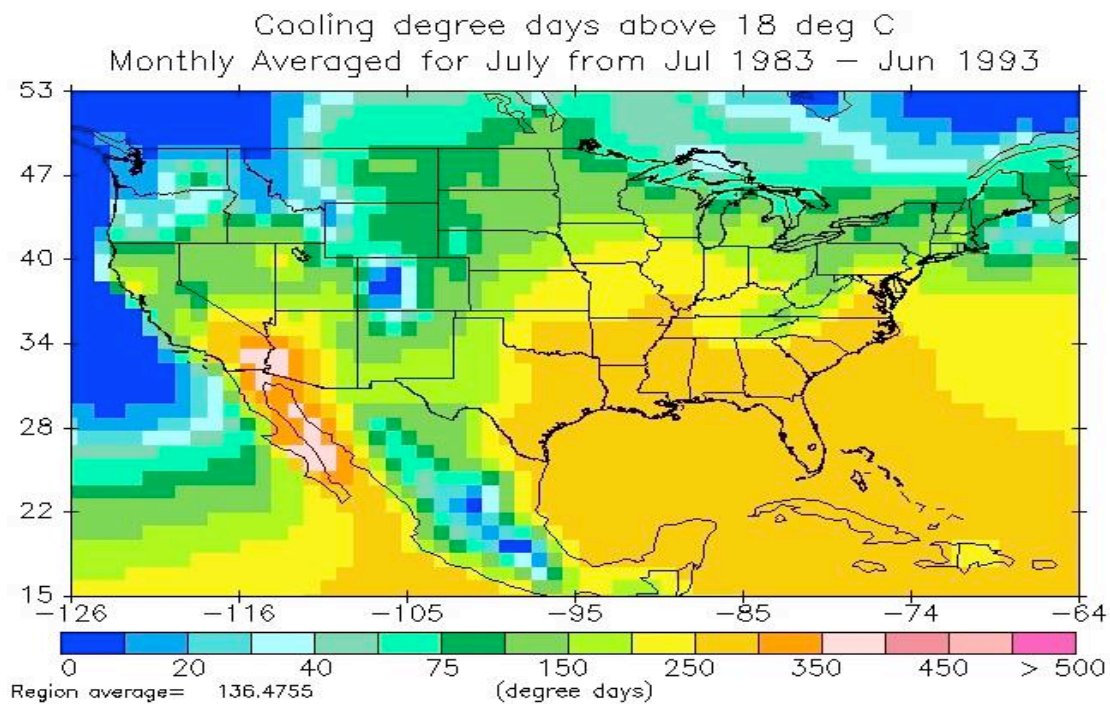


Fig. 3 - U.S. comparison of 1983 to 1993 and 1993 to 2003 decadal Cooling Degree Days.

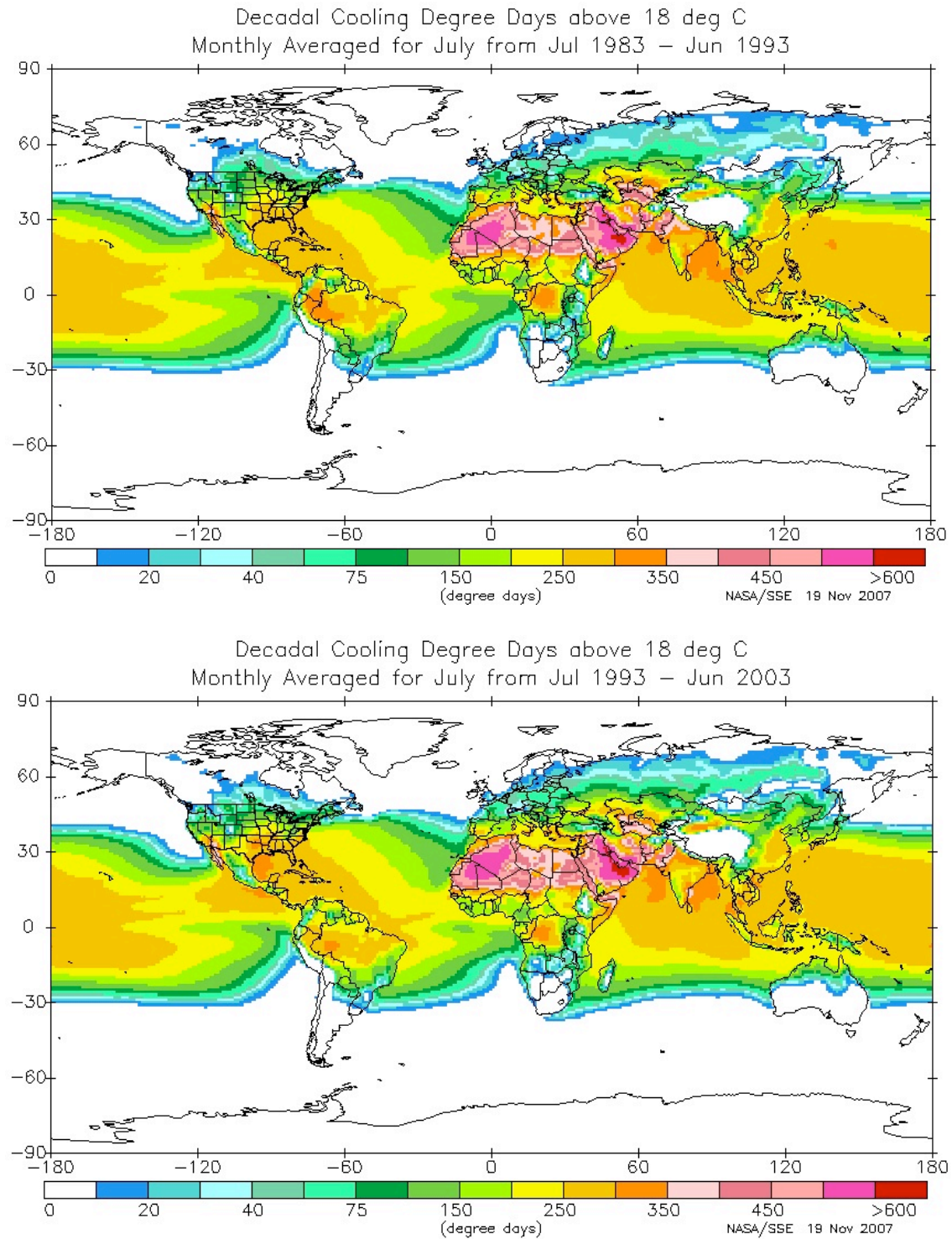


Fig. 4 - Global comparison of 1983 to 1993 and 1993 to 2003 decadal Cooling Degree Days.

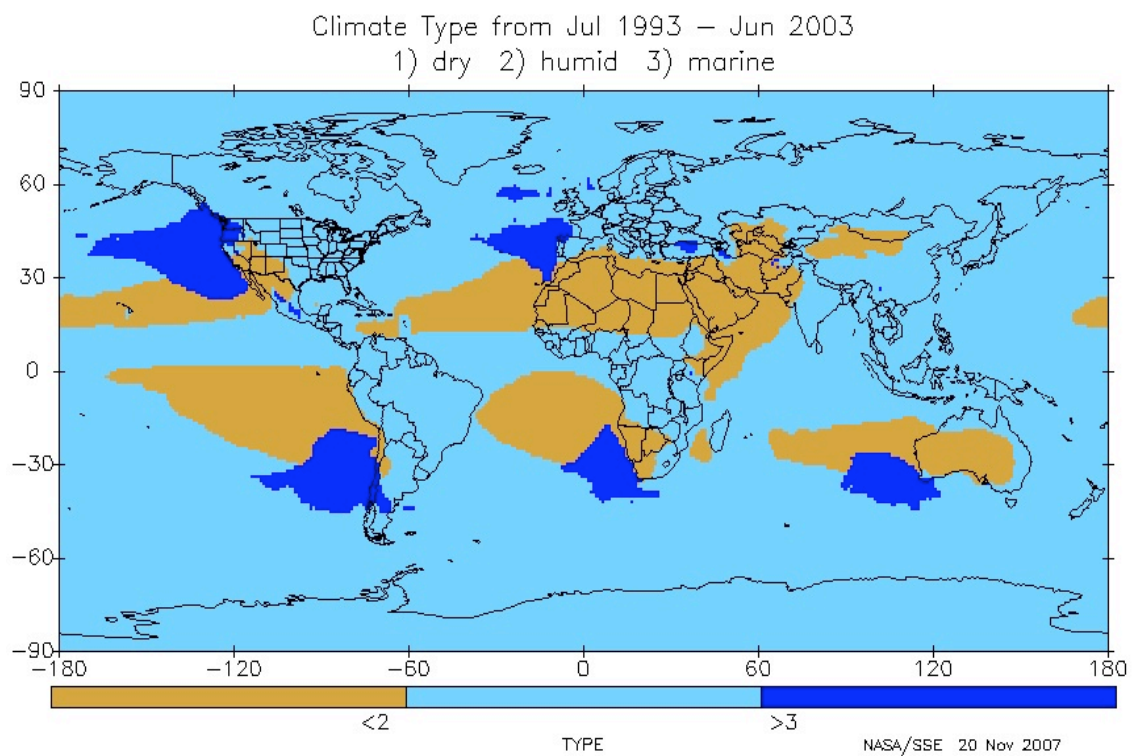
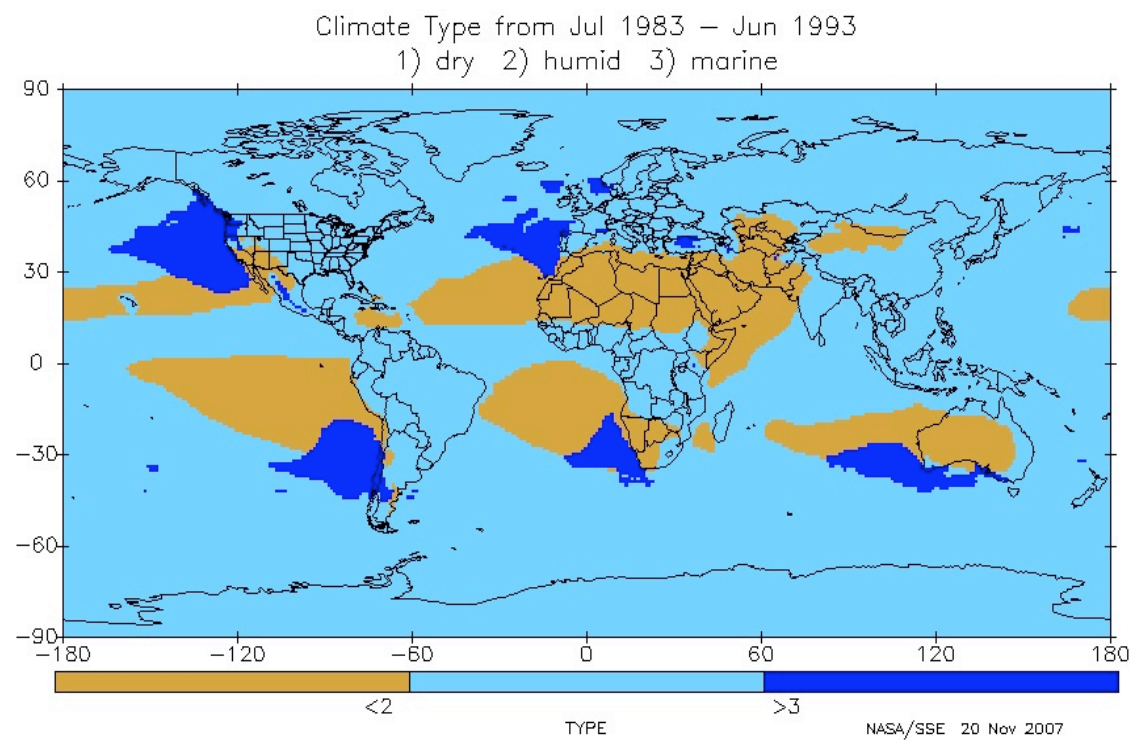


Fig. 5 - Estimate of climate types over the globe based on NASA one-degree spatial resolution data.



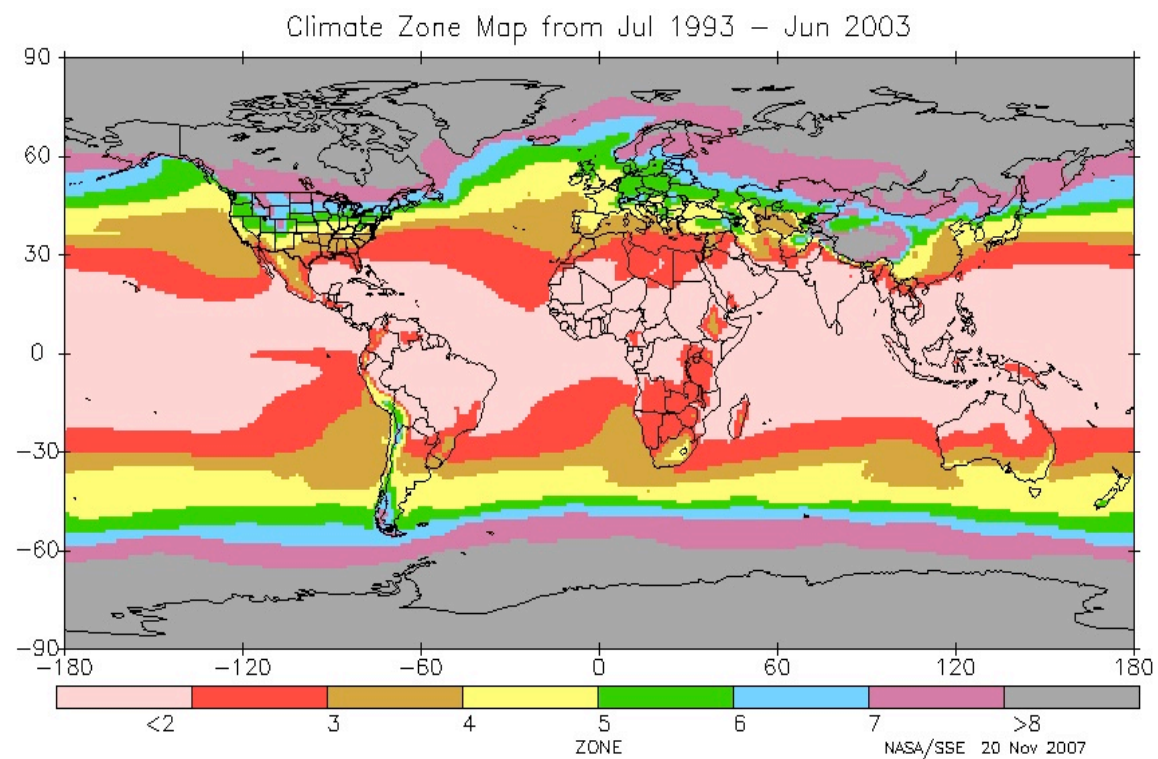
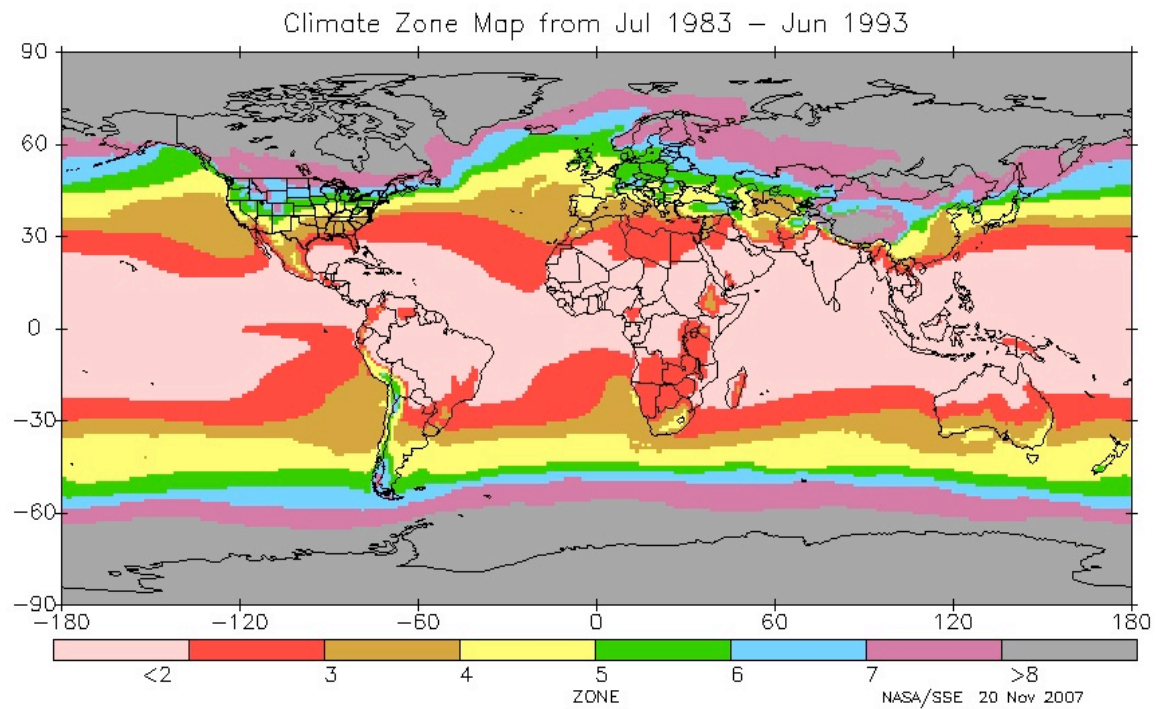


Fig. 6 - One-deg cell size estimate of Briggs et al. climate zone distribution over the globe based on NASA one-deg spatial resolution data. Boundaries are based on meteorological conditions instead of political considerations in this analysis.

**85 % CRITERIA  
FOR WEATHER STATION SELECTION**

**1. > OR = 20 ONE-HOURLY  
OBSERVATIONS/DAY.**

**2. 23/25/26 DAYS PER MONTH OF DATA  
DEPENDING ON TOTAL DAYS/MONTH.**

Fig. 7 - NASA criteria for selecting quality meteorological ground-site data from NCDC archives. NOAA documentation indicates uncertainty in the ground site temperature data is approximately 0.5 deg C.

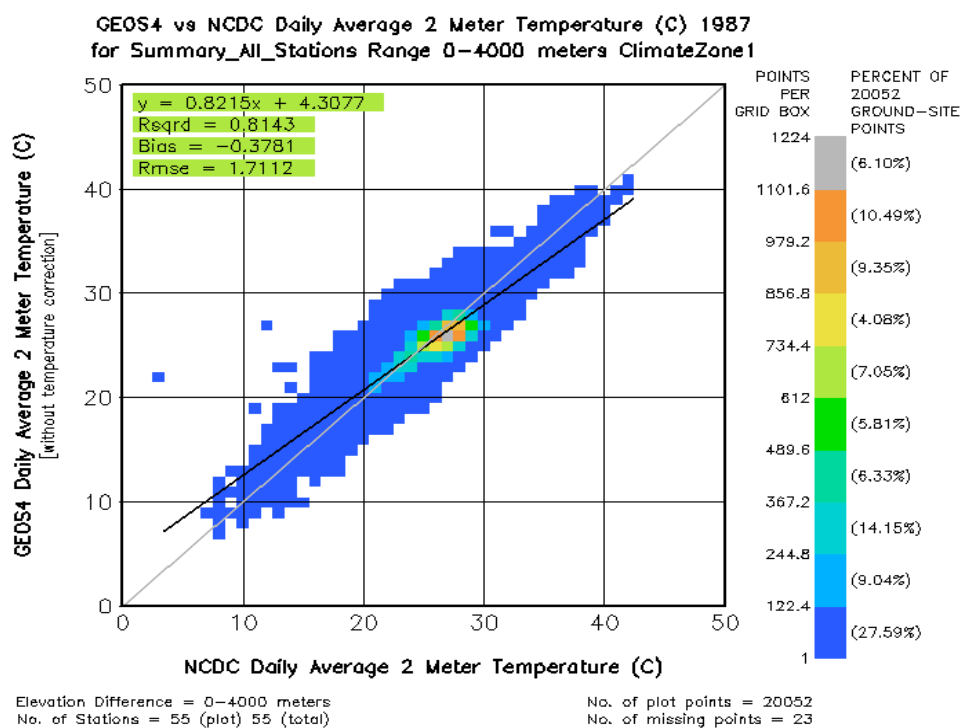
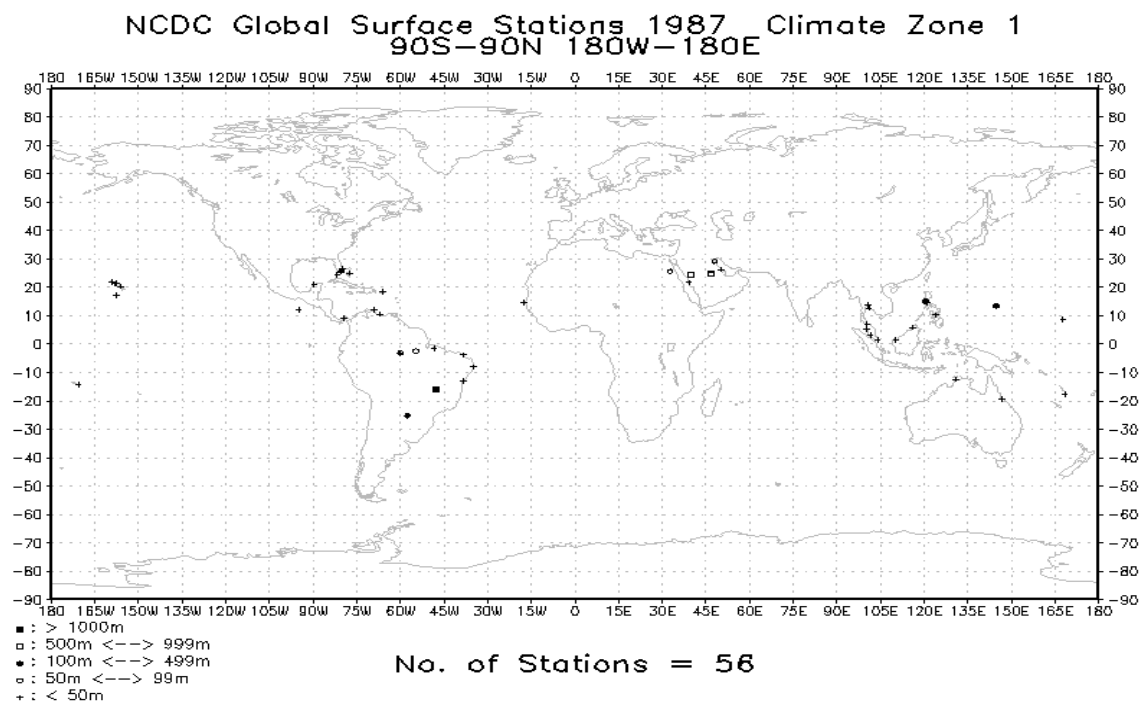


Fig. 8 - Climate Zone 1 selected ground-site locations and accuracy comparison of ground site data with NASA GEOS-4 reanalysis data. Topography-based lapse-rate corrections not yet applied.



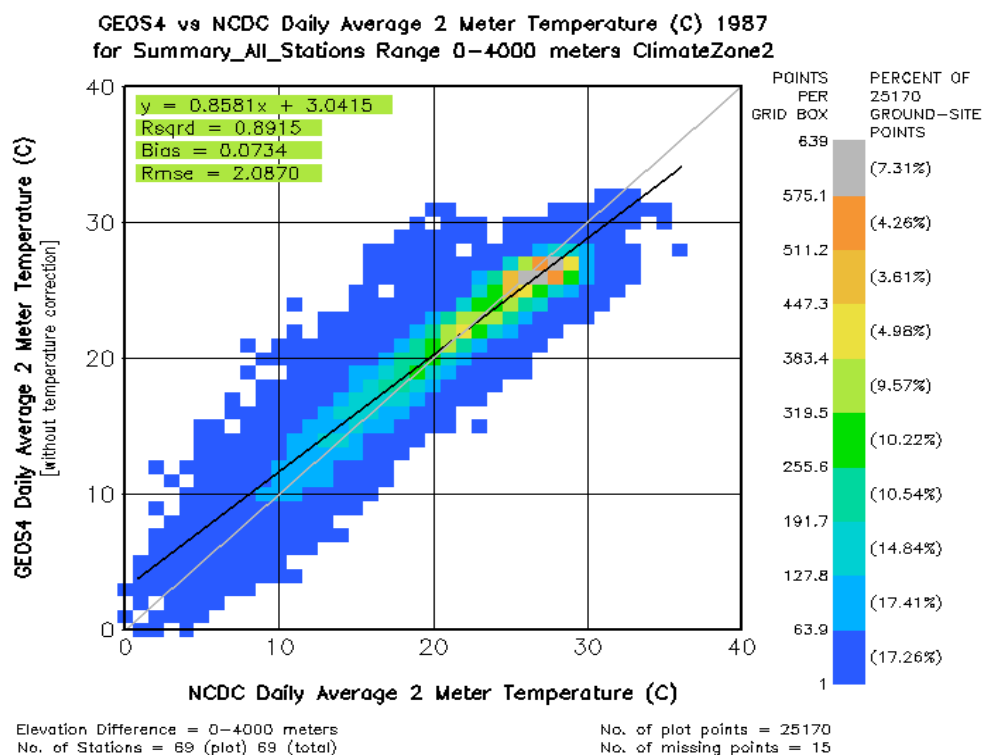
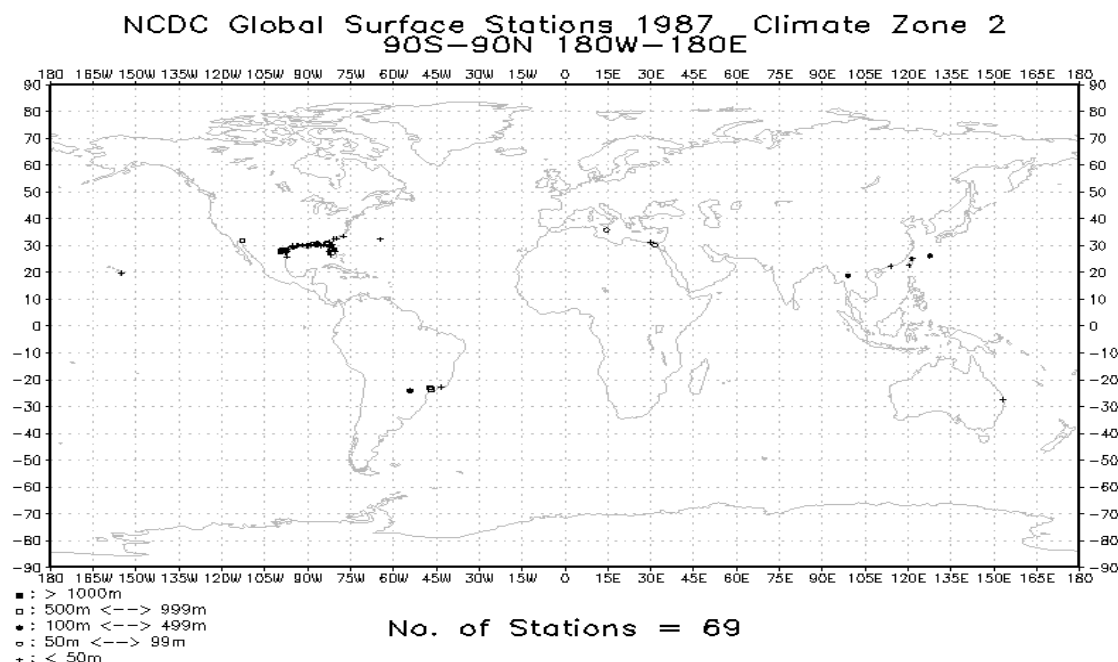


Fig. 9 - Climate Zone 2 selected ground-site locations and accuracy comparison of ground site data with NASA GEOS-4 reanalysis data. Topography-based lapse-rate corrections not yet applied.

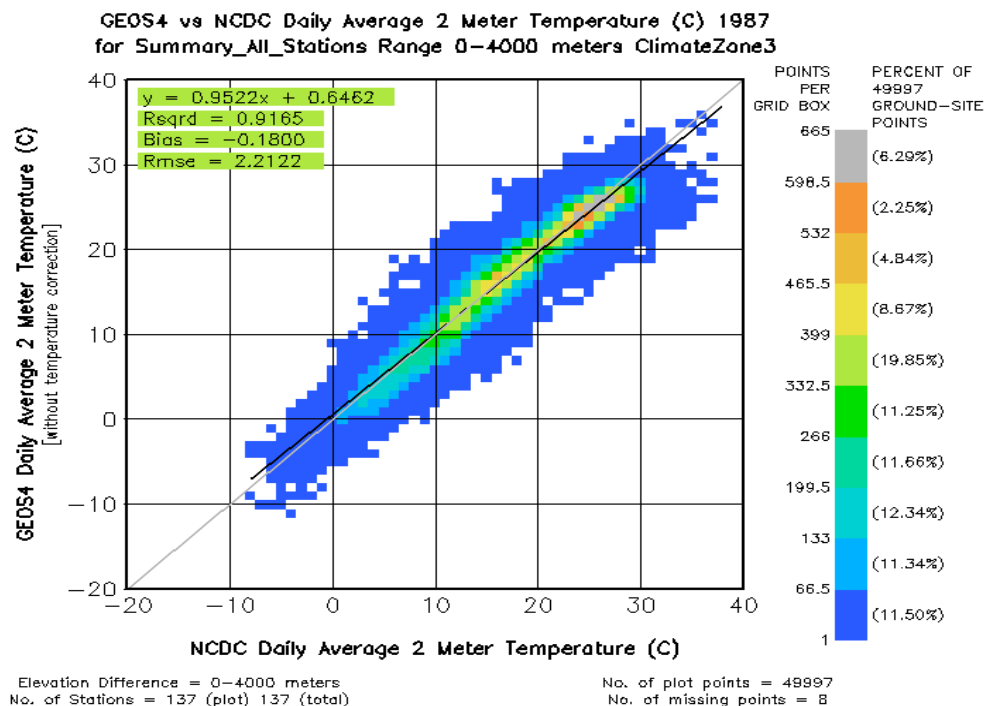
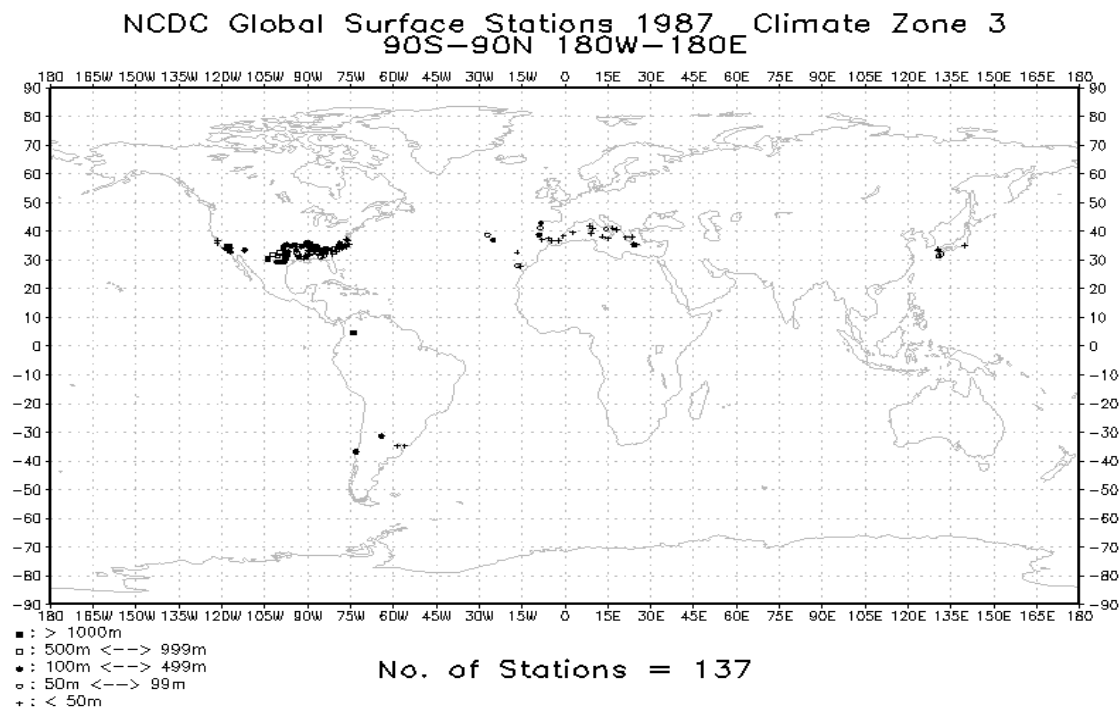


Fig. 10 - Climate Zone 3 selected ground-site locations and accuracy comparison of ground site data with NASA GEOS-4 reanalysis data. Topography-based lapse-rate corrections not yet applied.

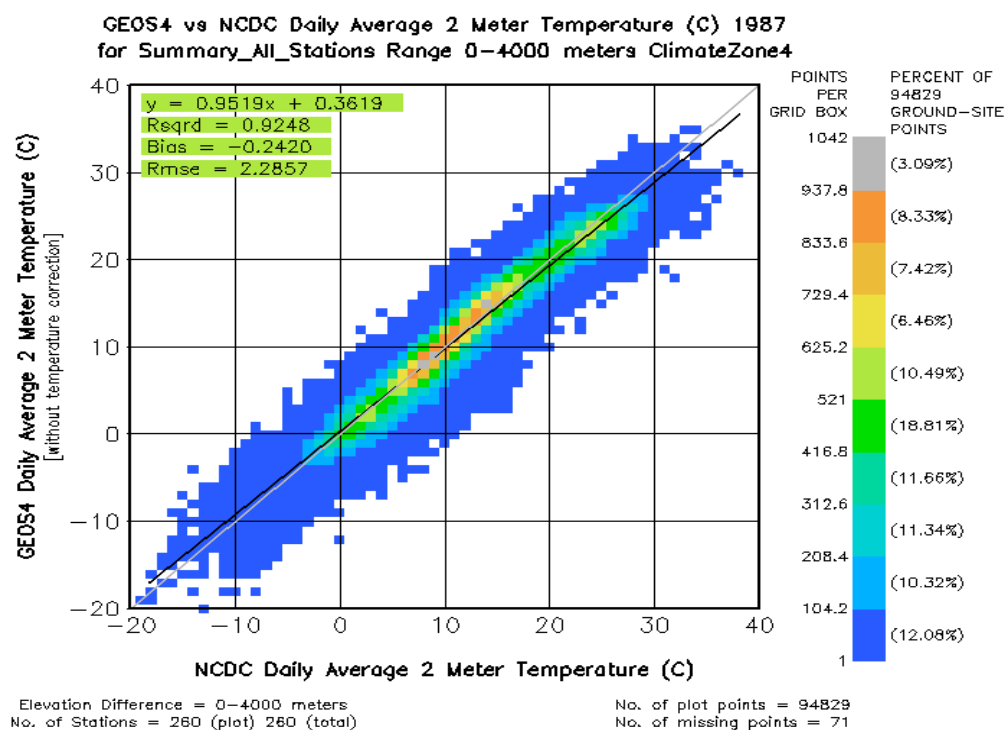
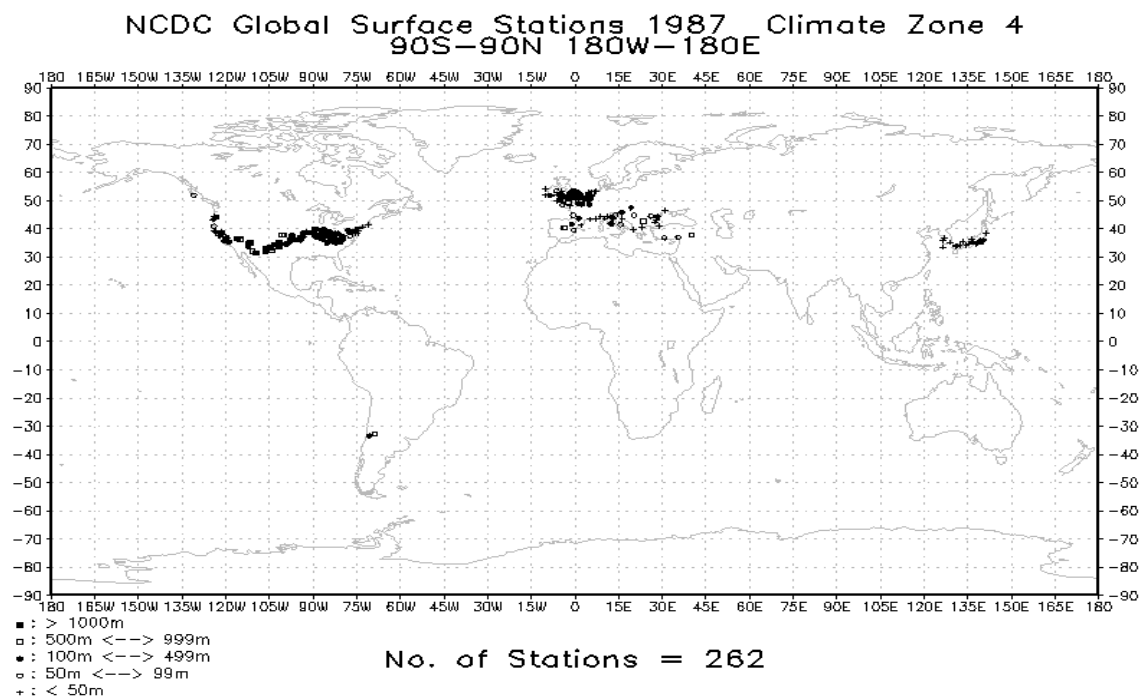


Fig. 11 - Climate Zone 4 selected ground-site locations and accuracy comparison of ground site data with NASA GEOS-4 reanalysis data. Topography-based lapse-rate corrections not yet applied.

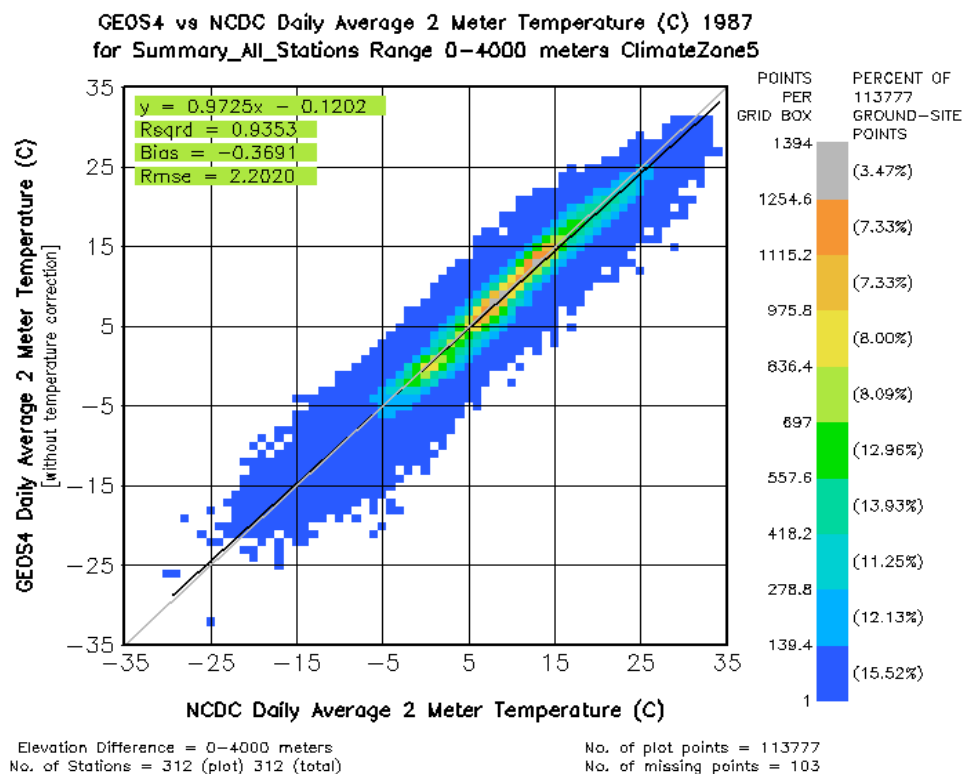
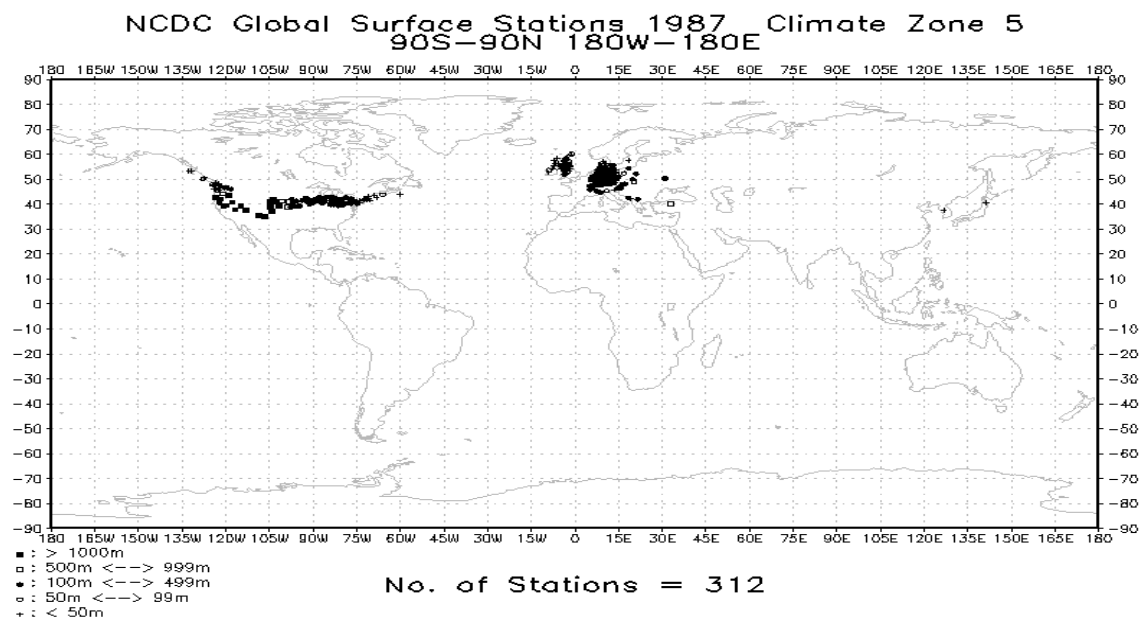


Fig. 12 - Climate Zone 5 selected ground-site locations and accuracy comparison of ground site data with NASA GEOS-4 reanalysis data. Topography-based lapse-rate corrections not yet applied.

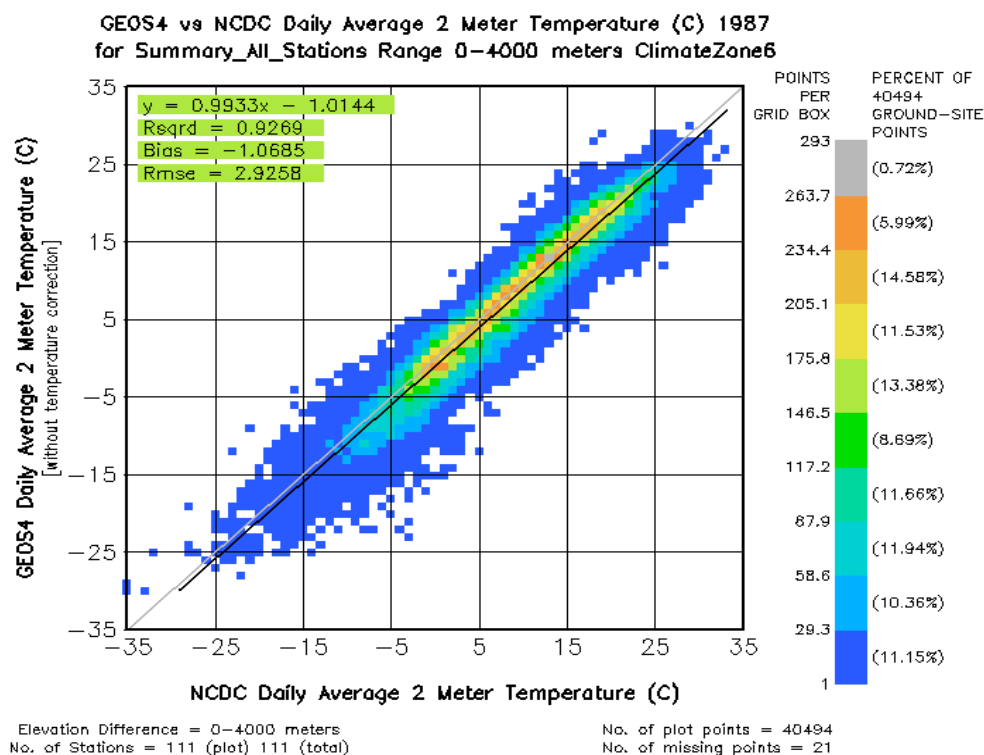
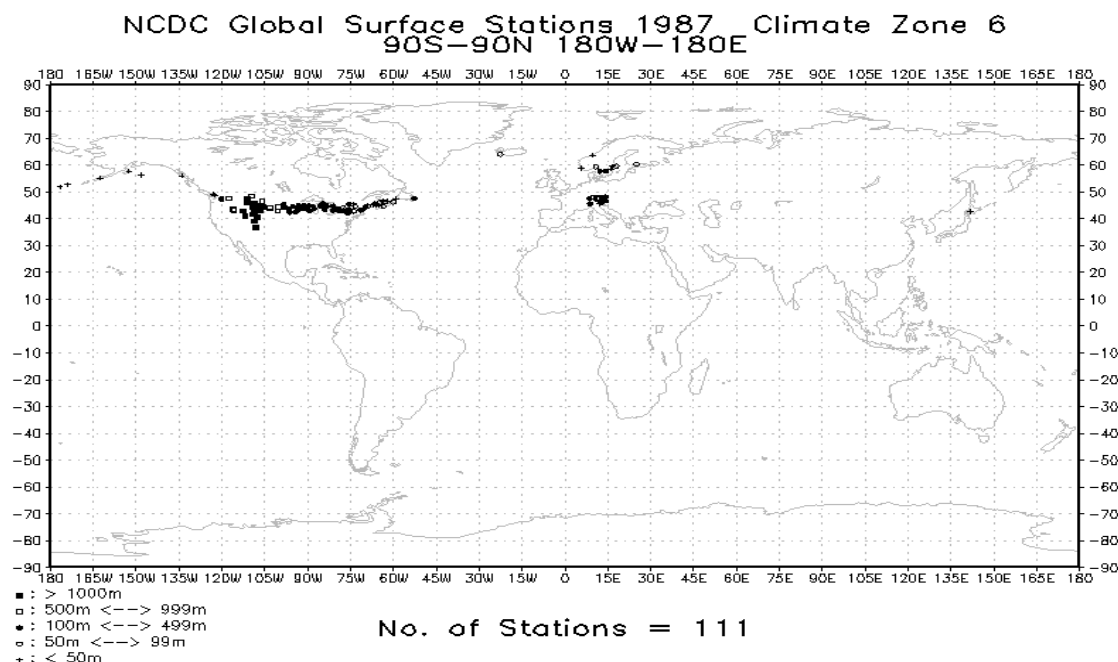


Fig. 13 - Climate Zone 5 selected ground-site locations and accuracy comparison of ground site data with NASA GEOS-4 reanalysis data. Topography-based lapse-rate corrections not yet applied.

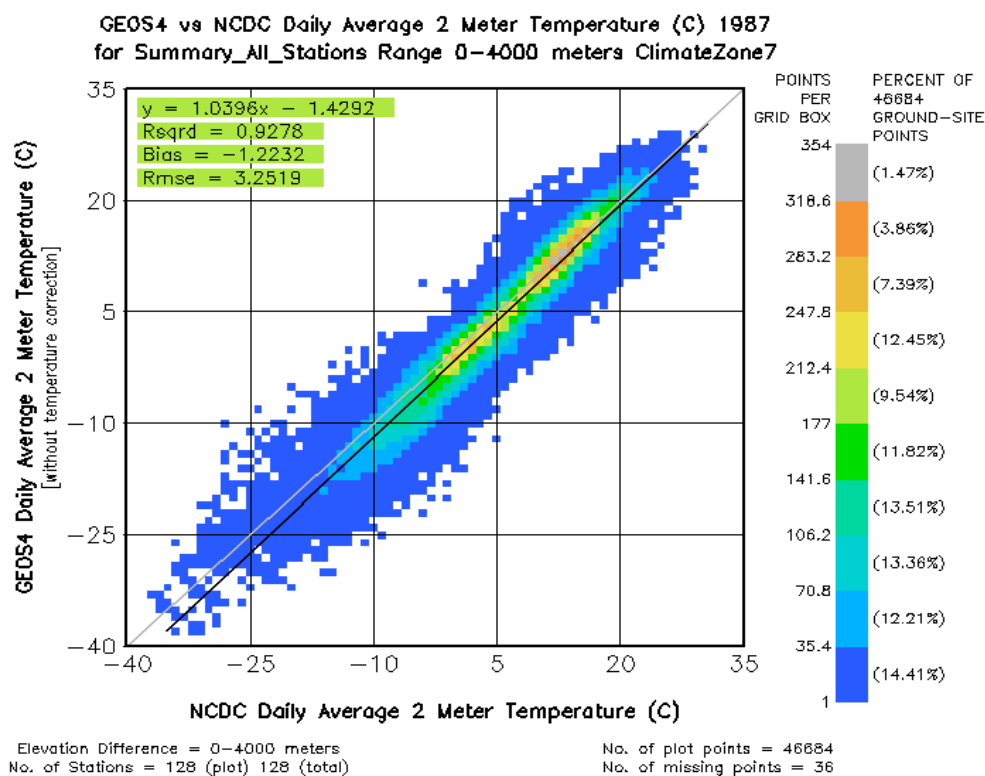
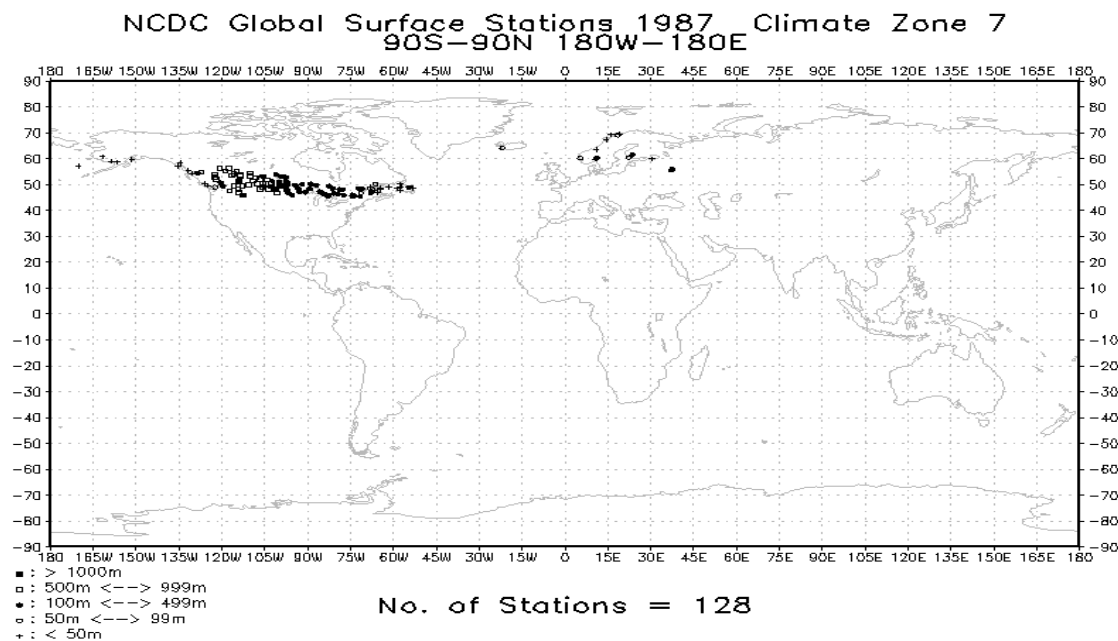


Fig. 14 - Climate Zone 7 selected ground-site locations and accuracy comparison of ground site data with NASA GEOS-4 reanalysis data. Topography-based lapse-rate corrections not yet applied.



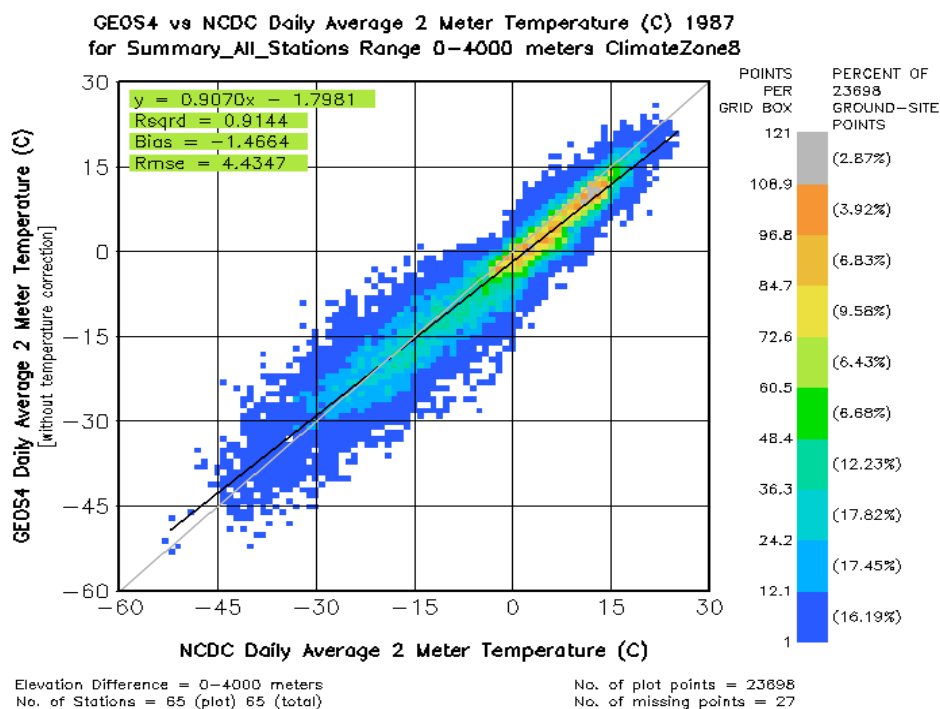
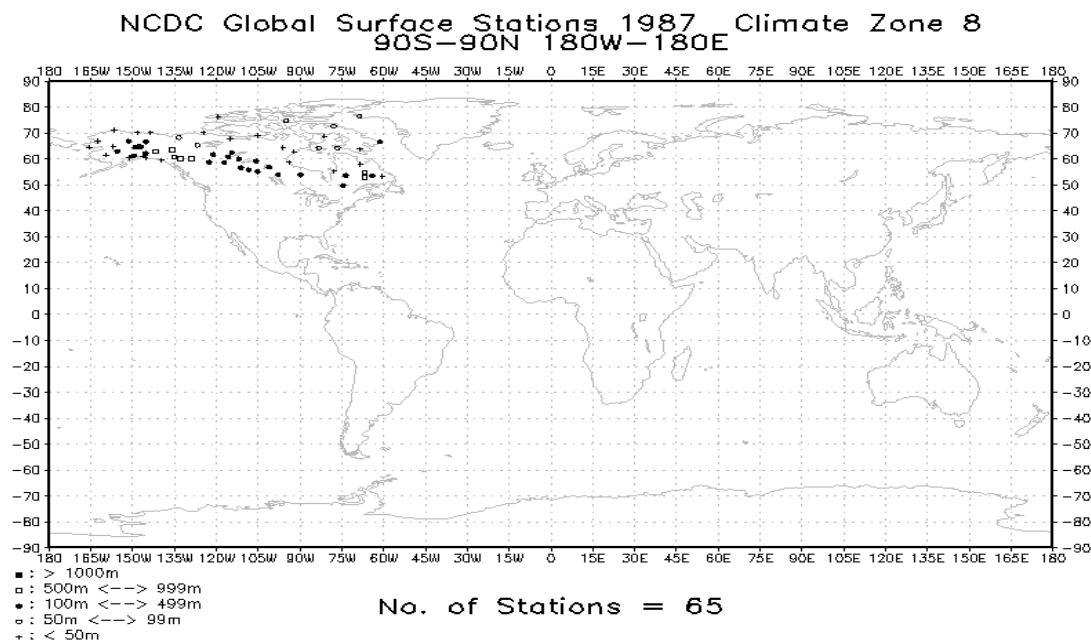
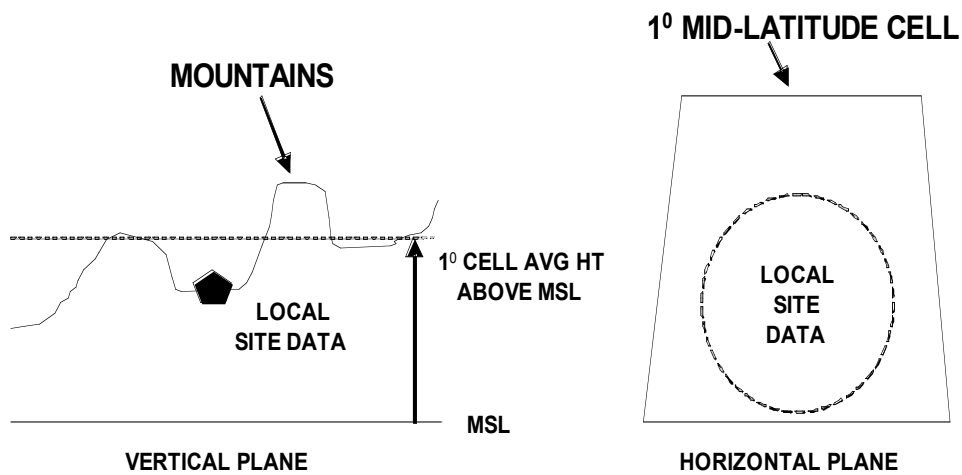


Fig. 15 - Climate Zone 8 selected ground-site locations and accuracy comparison of ground site data with NASA GEOS-4 reanalysis data. Topography-based, lapse-rate corrections not yet applied. Much of the scatter for all climate zones is probably caused by ground site height-to-satellite cell height differences in mountains and valleys and/or heat-island effects in cities.

## REANALYSIS MODEL CELL VERSUS NCDC LOCAL-SITE GEOMETRY



**REANALYSIS TEMPERATURES, WINDS, PRESSURES, ETC. MAY NEED LOCAL  
CORRECTIONS IN MOUNTAINS & CITIES.**

Fig. 16 – Typical reanalysis model versus local site conditions in mountains.

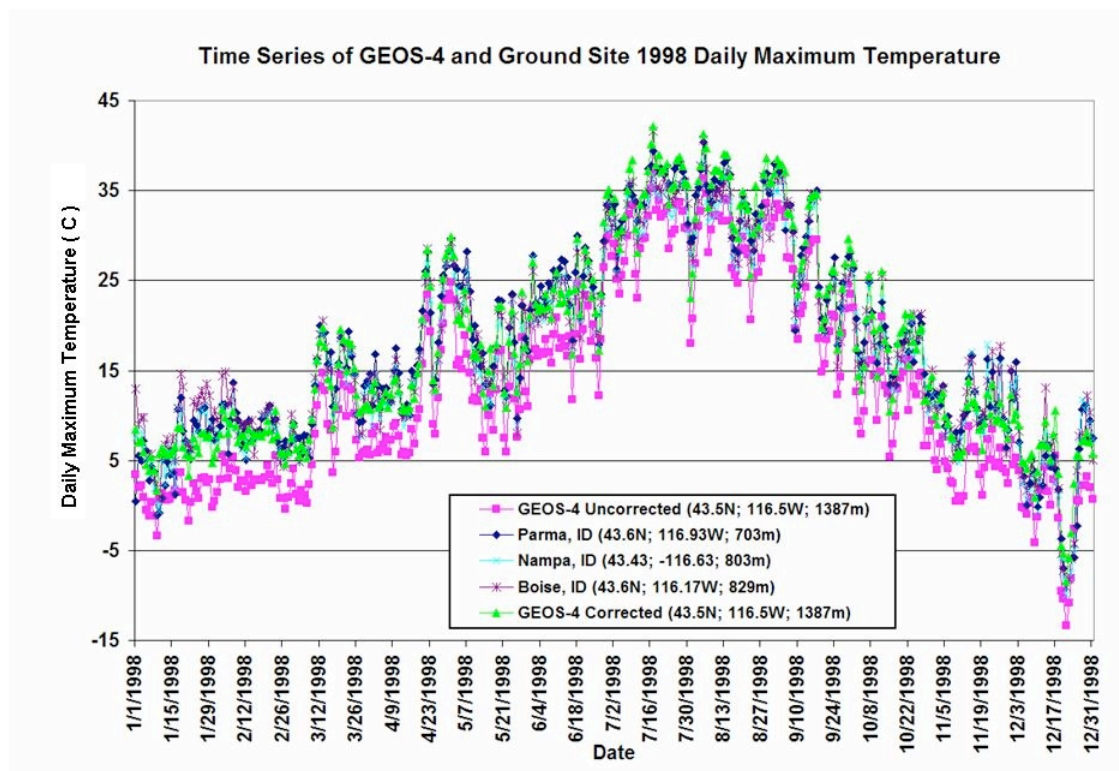


Fig. 17 - Effect of an approximate lapse-rate correction when site heights of Parma, Nampa, and Boise, ID (703 to 829 m) are very different than the GEOS-4 cell height (1387 m). Purple-symbol uncorrected GEOS-4 values are lapse-rate corrected (green symbols) to the average altitude of Parma, Nampa, and Boise to provide improved agreement.

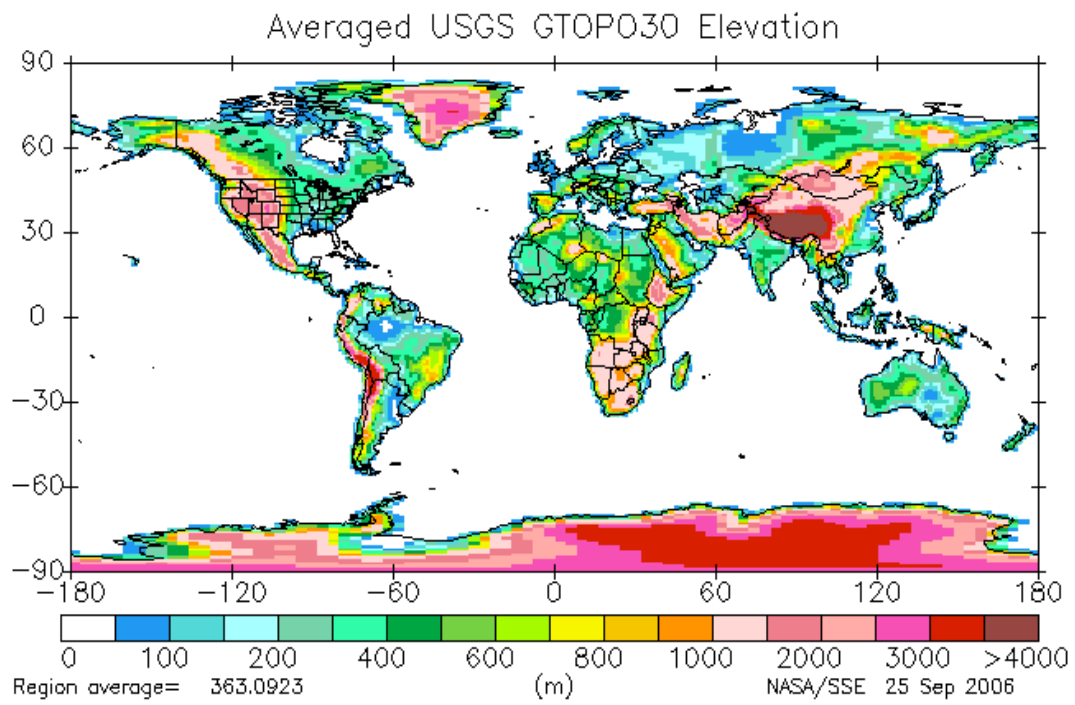


Fig. 18 – Topography source used in NASA reanalysis models. Height accuracy is approximately 1 meter for each 1-deg cell.